MTR-264

STUDIES IN DISPLAY SYMBOL LEGIBILITY

Part XIV. The Legibility of Military Map Symbols on Television

SEPTEMBER 1966

M. Marsetta
D. Shurtleff

Prepared for

DEPUTY FOR ENGINEERING AND TECHNOLOGY
DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 7030

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Prepared by
THE MITRE CORPORATION
Bedford, Massachusetts
Contract AF19(628)-5165

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FOREWORD

This report is one of a series describing symbol legibility for television display. Additional information on this topic may be found in the following reports: "Studies of Display Symbol Legibility: The Effects of Line Construction, Exposure Time, and Stroke Width," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-249, February 1963; "Studies of Display Symbol Legibility, II: The Effects of the Ratio of Width of Inactive to Active Elements Within a TV Scan Line and the Scan Pattern Used in Symbol Construction," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-440, July 1963; "Studies of Display Symbol Legibility, III: Line Scan Orientation Effects," by B. Botha, D. Shurtleff, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-138, May 1966; "Studies of Display Symbol Legibility, IV: The Effects of Brightness, Letter Spacing, Symbol Background Relation, and Surround Brightness on the Legibility of Capitol Letters," by D. Shurtleff, B. Botha, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-134, May 1966; "Studies of Display Symbol Legibility, V: The Effects of Television Transmission on the Legibility of the Common Five-Letter Words," by G. Kosmider, The MITRE Corp., Bedford, Mass., ESD-TR-65-135, May 1966; "Studies of Display Symbol Legibility, VI: Leroy and Courtney Symbols," by D. Shurtleff, and D. Owen, The MITRE Corp., Bedford, Mass., ESD-TR-65-136, May 1966; "Studies of Display Symbol Legibility, VII: Comparison of Displays at 945- and 525-Line Resolutions," by D. Shurtleff, and D. Owen, The MITRE Corp., Bedford, Mass., ESD-TR-65-137, May 1966; "Studies of Display Symbol Legibility,VIII: Legibility of Common Five-Letter Words," by G. Kosmider, M. Young, and G. Kinney, The MITRE Corp., Bedford, Mass., ESD-TR-65-385, May 1966; "Studies of Display Symbol Legibility, IX: The Effects of Resolution, Size and Viewing Angle of Legibility," by D. Shurtleff, M. Marsetta, and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-65-411, May 1966; "Studies of Display Symbol Legibility, X: The Relative Legibility of Leroy and Lincoln/MITRE Alphanumeric Symbols," by D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-115, August 1966; "Studies of Display Symbol Legibility, XI: The Relative Legibility of Selected Alphanumerics in Two Fonts," by G. Kinney and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-116, August 1966; "Studies of Display Legibility, XII: The Legibility of Alphanumeric Symbols for Digitalized Television," by G. Kinney, M. Marsetta, and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-117, August 1966; and "Studies of Display Symbol Legibility, XIII: Studies of the Legibility of Alphanumeric Symbols in the BUIC Symbol," by G. Kinney and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-302, August 1966.

ABSTRACT

The speed and accuracy with which five subjects identified military map symbols were determined with five different resolutions in lines per symbol height on a television monitor in three experiments. The first two experiments indicated that the minimum acceptable resolution is approximately 17 lines even after considerable practice. The third experiment indicated that a slightly lower resolution is permissible only with an optimum contrast of detail and a carefully selected and maintained television system. Recommendations are made for field installations.

REVIEW AND APPROVAL

This Technical Report has been reviewed and is approved.

James D. Baker
JAMES D. BAKER
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SECTION I

INTRODUCTION

Military map symbols, like those shown in Figure 1*, are used to designate the arm or branch of a military unit (such as artillery), the size of the unit (a company), whether it's airborne or armored, and so on. These symbols often appear on military maps[1] indicating the geographic location of the unit. They appear with alphanumeric symbols which indicate additional information about the unit, such as its number (the 437 regiment), whether it is a direct support unit or a general support unit, and so on.

In some operational situations, military maps and their associated symbology are displayed on closed-circuit television. For example, television might be used to transmit information from a field station to a command post, to route information to various locations within a command post, or to transmit information from one command post to another. If transmitted military information of this type is to be used effectively, then it is necessary to display symbols with a size and resolution which enables the display operator to identify them accurately and quickly.

Previous investigations of the legibility of television displays[2,3,4,5] have established the minimum symbol resolution (10 horizontal, active

* The numbers under the map symbols correspond to the numbers on Tables II through VI and X through XIII.

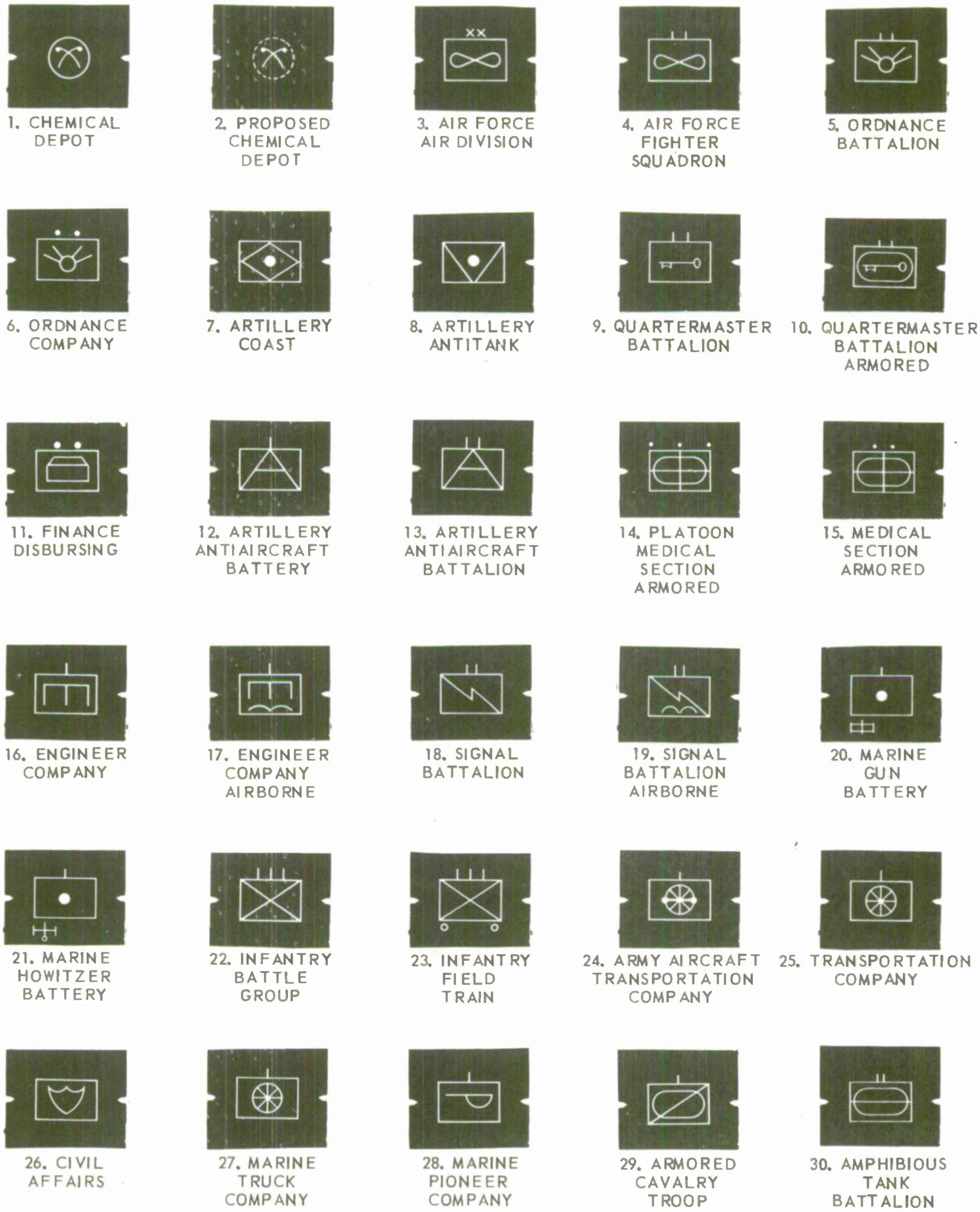

Figure 1. The Thirty Map Symbols used in this Study.

scan lines per symbol height) and visual size (16 minutes of arc) required for accurate identification of alphanumeric symbols. Similar information is needed for military map symbols.

The plan of the present investigation of the legibility of televised military symbols was guided, in part, by knowledge of the requirements for the accurate identification of alphanumeric symbols. Since military symbols and alphanumeric symbols appear together, it seemed reasonable to fix the viewing distance for the investigation of televised military symbols at a value where the observer would be able to identify televised alphanumeric symbols rapidly and with minimal error. With the viewing distance thus fixed by the requirements for alphanumerics, the size and resolutions of televised map symbols were varied to determine which values were needed for fast and accurate identification of the map symbols.

The results showed that when an observer is seated at a distance which will enable him to accurately identify alphanumeric symbols (distance at which symbols, when resolved by 10 active television scan lines, subtend a visual size of 16 minutes of arc), he required a resolution of approximately 17 lines per map symbol height to accurately identify the map symbols. At a resolution of 17 lines, the height of the map symbols subtended a visual size of approximately 27 minutes of arc. For a display of maximum quality when the viewers are well practiced, a resolution of 11 lines and a visual size of 18 minutes of arc may be satisfactory.

SECTION II

METHODS AND PROCEDURES

Five subjects between the ages of 23 and 40 years were screened for normal near and far acuity, color vision, and phoria.

The military map symbols (Figure 1) were selected from an Army field manual on military symbols.[1] The 30 symbols selected required the viewer to identify both gross and fine detail of the symbols in order to respond correctly. For example, perception of gross detail would enable the observer to distinguish one military branch from another, such as a chemical branch from a signal branch. However, in order to distinguish among units of the same branch (a chemical depot from a proposed chemical depot), he would be required to perceive fine detail such as a broken line from a solid line. The perception of other fine detail was required for accurate identification of map symbols of the same branch such as, "xx" from "||" of the Air Force units, ".." from "||" of the Ordnance units, "⊢⊣" from "⊏⊐" of the Marine gun battery units, and so on.

The symbols were photographed on 35 mm film for use in a modified motion analyzer. The symbols were projected onto the screen of the motion analyzer and picked up by a General Precision, 945-line television camera (Model 820, Serial No. 154) and displayed in the center

of the raster of a 945-line General Precision monitor (Model CQE 14/945). Symbol resolution was varied by a Pan Cinor "70" zoom lens. The symbols were light on a dark background with a width of 150 percent of height and a stroke-width of six percent of height.* The symbols had a brightness of 20 foot-Lamberts and a background of 2 foot-Lamberts.

Since the subjects were unfamiliar with military symbols, they had to learn the names of the symbols before the experiment. Flash cards were made up for this purpose with the military symbol printed on one side of the card and the name of the symbol printed on the opposite side of the card. The subjects were given the cards and requested to learn the names of the symbols in the same way they would learn the meaning of words in a foreign language. After training with the flash cards, the subjects were tested by the experimenter to make certain they could name each symbol without error. The test was conducted by showing the symbols to the subjects one-at-a-time and requiring them to name each one. The subjects were presented with a complete list of symbols, and the list was repeated until such time that the subjects were able, on two consecutive presentations of the entire list, to name each symbol without error.

Following the preliminary training, the subjects identified military symbols resolved by 11, 14, 17, 20, and 23 lines per symbol

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* The width and stroke-width of the symbols represent the average values of a random sample of symbols taken from the Army field manual.[1]

height with visual sizes of 18, 22, 27, 32, and 37 minutes of arc. These values of resolution were determined before the experiment by having an observer identify the military symbols at resolutions ranging from 10 to 30 lines per height. The data for the observer suggested that a range of resolutions from 11 to 23 lines per symbol height would be worth a more detailed investigation.

Each subject had five experimental sessions. Each session required the subject to make five identifications of each symbol, in one of the five resolutions, for a total of 150 identifications per session. Each subject was given the resolutions in a different order, arranged so that each resolution appeared an equal number of times in each ordinal position, e.g., first, second, third. The order approximated one in which each resolution preceded and followed each of the other resolutions an equal number of times.

During a session the subject was seated at a table which was located directly in front of the television monitor. The table was provided with (a) a headrest to fix the distance between the observer and the television screen, (b) a pushbutton switch which when pressed displayed a symbol on the monitor screen, and (c) a microphone which shut off the display when the subject orally identified the symbol. Both the subject's accuracy and speed of symbol identification were recorded.

The ambient room illumination was 5 to 7 foot-candles of diffuse Standard Cool-White fluorescent light at the subject's station. The unused portion of the monitor screen was masked by gray cardboard to eliminate potentially annoying or distracting reflections from the monitor screen.

After completing the five sessions, the subjects were asked to repeat the experiment. The same five resolutions were used again, but the subjects were given them in reverse of the first order. The reason for repeating the experiment was that the television equipment broke down several times necessitating long delays in data gathering. Also, it appeared that considerable additional improvements in the identification of the symbols came about with practice in the experiment. The data for the first run through the experiment are reported in Part I of the results section and the data for the second run through the experiment are reported in Part II.

Although the results for Part II gave an estimate of the effects of practice on accuracy of identification, there was an additional need for estimating the potentially harmful effects caused by several components of the television equipment. Even though the 945-line television system was new and of good quality, some difficulty was experienced in achieving and maintaining a high quality display. Part of the difficulty was caused by the vidicon tube (RCA 8507)

which deteriorated progressively over the experimental sessions. A second source of difficulty was maintaining a sharply focused display with the zoom lens over the range of resolutions used. In previous work with television, a fixed focal-length lens was used and the camera-to-screen distance was varied to obtain different values of symbol resolution. In the present study, a zoom lens was used because it was easier for the experimenter to change symbol resolution. In addition, zoom lens attachments are used in many television applications, and the results might better apply to situations in which these lens attachments are used. The zoom lens was a good quality Pan Cinor "70" with a variable focal length ranging from 17.5 mm to 70 mm.

Because of the questionable quality of the television display, four of the five subjects were rerun at symbol resolutions of 11 and 9 lines per symbol height after the vidicon tube had been replaced and a fixed focal-length lens mounted on the camera in place of the zoom lens. Finally, the same four subjects were rerun for two additional sessions to evaluate the effect of the lens system on symbol identification, since it was felt that the results for Parts I and II might be a joint product of both the vidicon tube and the lens system. During one session, the fixed focal-length lens was used. For the other session, the zoom lens was used. The order in which the lenses were used was counterbalanced for the four subjects. The data collected for these two supplemental experiments are reported in Part III.

SECTION III

RESULTS OF PART I

The accuracy of identification at each of the five resolutions is shown in Table I and Figure 2. The figure indicates that the average percentage of correct identifications for the five subjects was similar for resolutions of 17, 20, and 23 lines, but declined markedly for resolutions of 14 and 11 lines per symbol height. The table shows that the reduction in the number of correct identifications at 11 and 14 lines was also accompanied by an increase in differences among the subjects in their ability to identify the symbols. The differences among subjects are reflected by the size of the standard deviation, which is large for the two lowest resolutions but comparatively negligible for the three highest resolutions. Therefore, resolutions of 11 or 14 lines were unsatisfactory for two reasons: the low mean accuracy of identification and the increase in variability among the subjects.

While the above clearly shows the relation of accuracy to resolution, it is of some interest to see how the errors were distributed among individual military symbols. Tables II through VI have been constructed for this purpose; the rows indicate the symbol shown and the columns indicate the frequency with which each symbol was called one of the other symbols. The first feature to notice about the matrices

Table I. Accuracy of Identification in Number Correct for Part I

Subjects	Lines Per Symbol Height				
	11	14	17	20	23
1	96	147	148	150	149
2	117	141	148	150	149
3	36	99	141	146	150
4	73	86	146	146	149
5	54	124	145	144	144
$\bar{X}$	75.2	119.4	145.6	147.2	148.2
SD	28.8	23.6	2.6	2.4	2.1
Mean Percent Correct	50	80	97	98	99

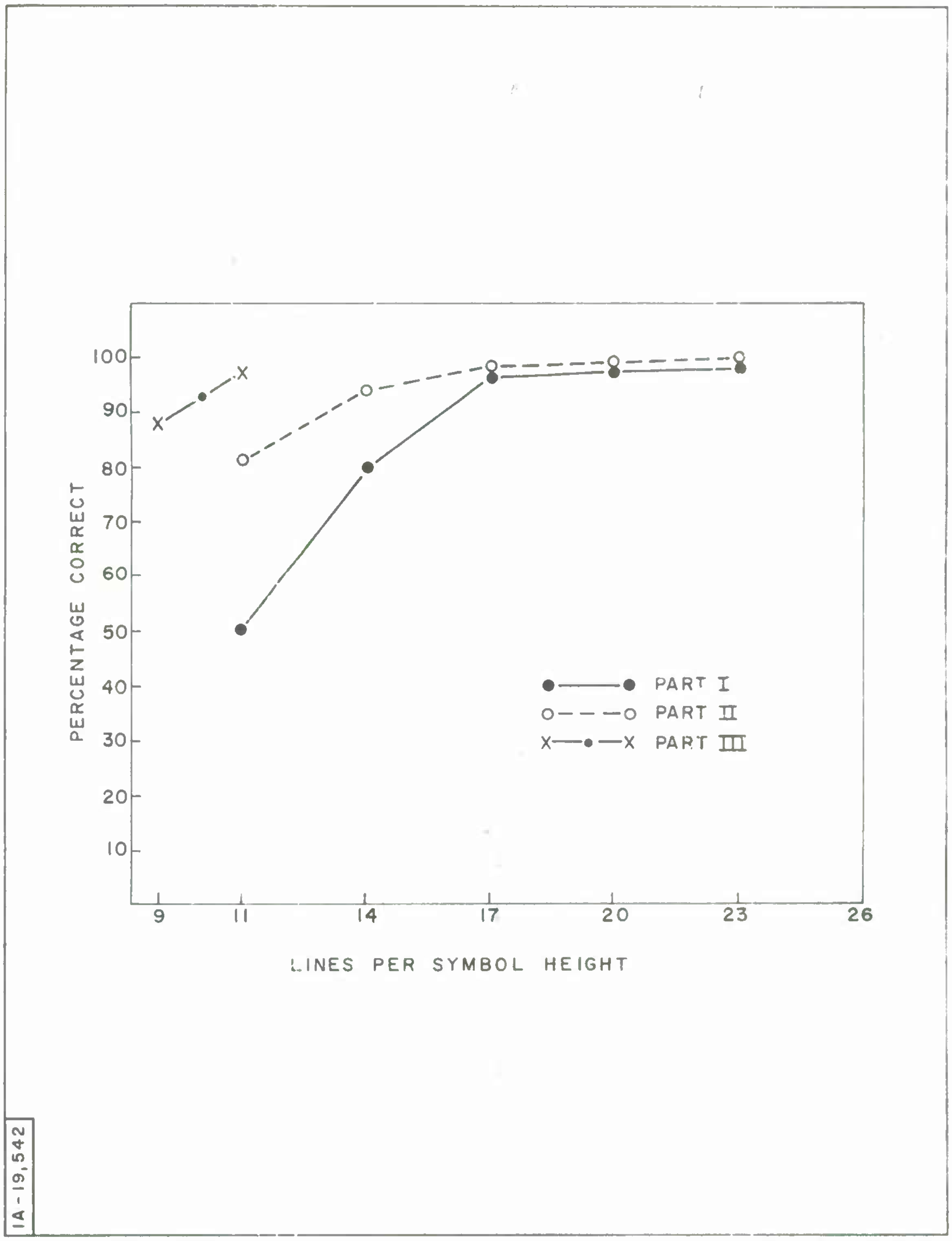

Figure 2. Accuracy of Identification in Percentage Correct for the Three Parts of the Experiment.

Table II

Symbol Confusions for a Resolution of 11 Lines for Part I

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1		8																							1						9
2	5																														5
3				2					5	1	1		1																	12	22
4			2						6	1	3								1											12	25
5						4		10																1							15
6			1		3			2		1					1											1				1	10
7					1			2						5	1			2	1			1	1		1					1	16
8					1	2	2				2							1				1			1				1	1	12
9			2	1																				1						3	7
10				1					3		2				1			1											1	10	19
11	1	1	5										1	1	1															2	12
12													11																		11
13								1				6																			7
14							4												1				2						2	3	12
15				1			1			1	1			3			1	1				1	1			1				2	14
16							1				2			1	4		2					1									11
17				1						1	2				1	9												1	1	1	17
18							2				1		1	2	2							2	2			1	1			1	15
19							1	2			1	1				1	2	3				1	1			1					14
20							1														2										3
21																				17											17
22							3								1			1					1						6		12
23							4	1						1								1									7
24							2																		5	1					8
25								1			3													8							12
26			1			1		3			2				1		2											1		1	12
27					1	1																		7	12						21
28			1	2						2					1	1		2							1						10
29			2															4				1									7
30									2	4					2													1	1		10
	6	9	14	8	6	8	21	22	16	11	20	7	14	13	16	11	7	15	3	17	2	9	8	17	21	5	1	3	12	50	372

Table III

Symbol Confusions for a Resolution of 14 Lines for Part I

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1		6																													6
2	2																														2
3				3					4																						7
4			7											1								1									9
5						2		9																							11
6			1		7			3																							11
7										1				1	3							2	1						1		9
8						1	1				3														1						6
9			1		1																										2
10									4						1															4	9
11															1															2	3
12													1																		1
13												2																			2
14							1								1																2
15							1							1																	2
16									2		1			1			1														5
17							1									5										1				1	8
18							2							1								1									4
19					3													4				1	1								9
20																					3										3
21																				11											11
22							1																1						5		7
23								1																					1		2
24																															0
25																								5			1				6
26								1																							1
27																								3	9						12
28																															0
29																		3													3
30																															0
	2	6	9	3	11	3	7	14	10	1	4	2	1	5	6	5	1	7	0	11	3	5	3	8	10	1	1	0	7	7	153

Table IV

Symbol Confusions for a Resolution of 17 Lines for Part I

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1		1																													1
2	7																														7
3																															0
4			4																												4
5						3																									3
6					1																										1
7																															0
8																															0
9																															0
10																															0
11																															0
12																															0
13																															0
14																															0
15																															0
16																															0
17																															0
18																															0
19																															0
20																															0
21																				5											5
22																															0
23																															0
24																															0
25																								1							0
26																															1
27																															0
28																															0
29																															0
30																															0
	7	1	4	Ø	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	1	0	0	0	0	0	0	22

Table V

Symbol Confusions for a Resolution of 20 Lines for Part I

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1		1																													1
2	6																														6
3																															0
4			1																												1
5																															0
6					1																										1
7																															0
8																															0
9																															0
10																															0
11																															0
12																															0
13																															0
14																															0
15																															0
16																															0
17																															0
18																															0
19																															0
20																					1										1
21																				3											3
22																															0
23																															0
24																									1						1
25																															0
26																															0
27																															0
28																															0
29																															0
30																															0
	6	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	1	0	0	0	0	0	14

Table VI

Symbol Confusions for a Resolution of 28 Lines for Part I

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1																															0
2	1																														1
3																															0
4																															0
5						1																									1
6																															0
7																															0
8																															0
9																															0
10																															0
11																															0
12																															0
13																															0
14																															0
15																															0
16																															0
17																															0
18																															0
19																															0
20																					1										1
21																				4											4
22																															0
23																															0
24																									2						2
25																															0
26																															0
27																															0
28																															0
29																															0
30																															0
	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	2	0	0	0	0	0	9

is that the errors of identification are not spread uniformly throughout a matrix, but tend to be clustered in certain places. Secondly, the clustering of errors is comprised of symbol confusions that are "two-way" (or reciprocal) and some that are only "one-way." Examples of two-way confusions are, 2 was often called 1 and 1 was also often called 2; 30 was often called 21 and 21 was often called 30. On the other hand, other major sources of errors were only one-way. Examples in Table II are 2 and 3 were often called 30, but 30 was never called 2 or 3. These are only examples and the reader will find other confusions of both types by close inspection of the matrices.

A third point of interest is that some of the confusions are among units of different branches, e.g., Air Force units (2 and 3) with a tank unit (30); others are among units of the same branch, e.g., Marine gun battery with Marine howitzer battery. For a selected set of symbols at a resolution of 11 lines, errors between symbols denoting different branches accounted for 44 percent of the total error while errors for these same symbols involving confusions among units of the same branch accounted for only 27 percent of the total error. At a resolution of 14 lines, errors among units of different branches accounted for 32 percent of the total error while those among units of the same branch accounted for 46 percent of the total error. At resolutions of 17,

20, and 23 lines for the same selected set of symbols, there were no errors among units of different branches while confusions among symbols of the same branch accounted for all of the total error. Thus, as symbol resolution and size increased, there was a gradual decrease in the number of errors among units of different branches while the errors among units of the same branch either persisted or decreased more slowly, and thereby contributed increasingly to the total number of errors.

Therefore, 17 lines were needed for most of the subjects to distinguish among units of different branches, and some of the units of the same branch were still confused at 23 lines of resolution.

The speed of identification at each of the five resolutions is shown in Figure 3 and Table VII. Figure 3 shows that the break in the curve relating speed of identification to resolution occurred at 17 lines per symbol height as it did for accuracy of identification. Speed of identification was similar for resolutions of 17, 20, and 23 lines, but declined markedly for resolutions of 14 and 11 lines. Table VII shows that the decline in speed of identification was associated with an increase in differences among the subjects' individual speeds in identifying the symbols. These differences among the subjects in speed of identification are shown by the size of the standard deviation which is large for the two lowest resolutions and negligible for the three highest resolutions.

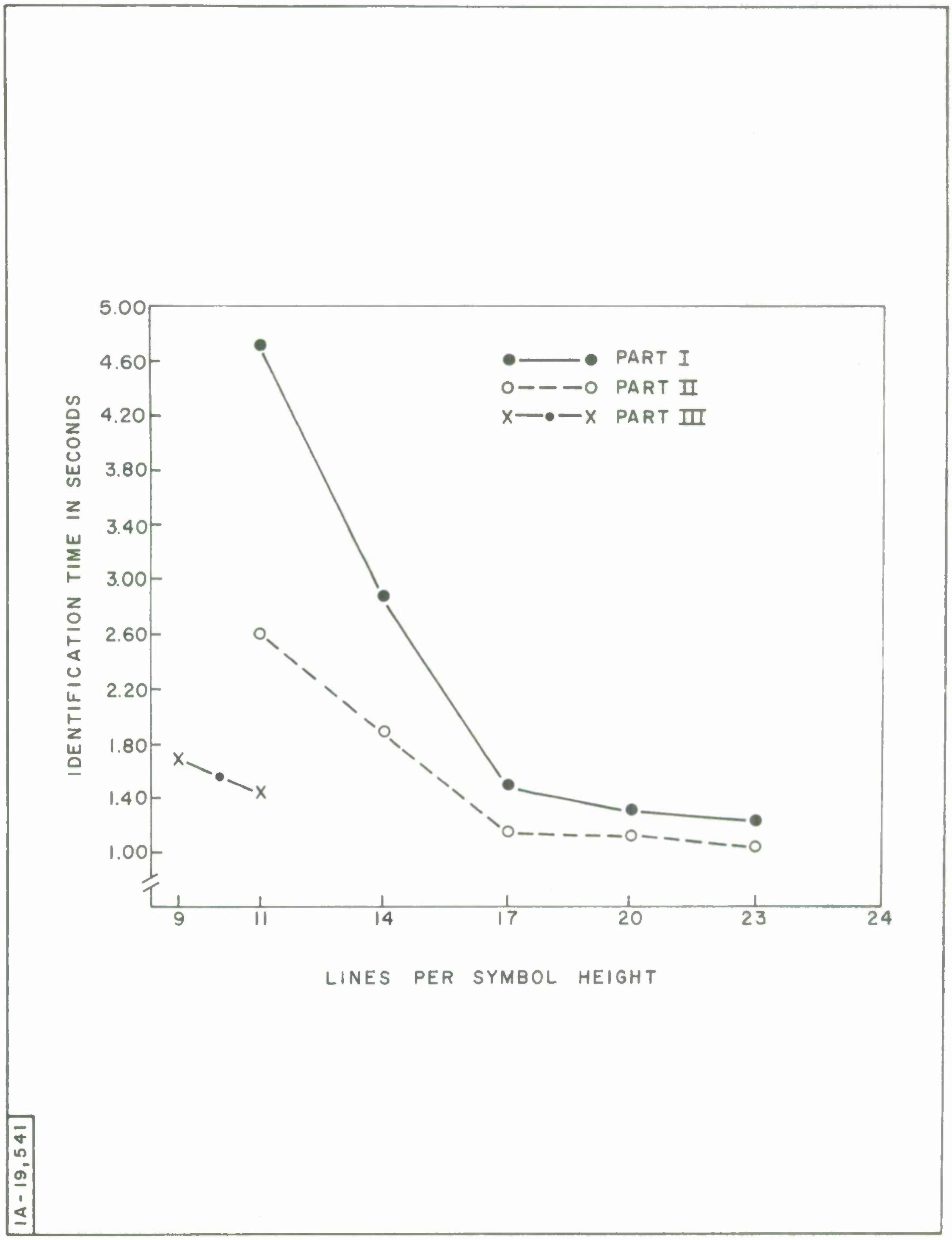

Figure 3. Speed of Identification in Seconds for Three Parts of the Experiment.

Table VII. Speed of Identification in Seconds for Part I

Subjects	Lines Per Symbol Height				
	11	14	17	20	23
1	6.61	3.66	1.79	1.50	1.33
2	1.59	1.66	1.11	1.23	1.19
3	8.00	5.04	1.95	1.21	1.44
4	3.30	2.09	1.13	1.27	1.06
5	4.05	1.97	1.45	1.30	1.36
$\bar{X}$	4.71	2.88	1.49	1.30	1.28
SD	2.31	1.28	.34	.10	.13

Therefore, resolutions of 11 or 14 lines were unsatisfactory for two reasons: the marked increase in symbol identification time and an increase in variability among the subjects.

Table VIII. Accuracy of Identification in Number Correct for Part II

Subjects	Lines Per Symbol Height				
	11	14	17	20	23
1	141	150	150	150	150
2	119	145	150	150	150
3	131	139	149	150	150
4	109	144	147	150	150
5	114	130	142	146	150
$\bar{X}$	122.8	141.6	147.6	149.2	150
SD	11.7	6.8	3.0	1.6	0
Mean Percent Correct	82	94	98	99	100

SECTION IV

RESULTS FOR PART II

As stated previously, the subjects were run through the experiment a second time. The accuracy of identification for Part II of the experiment is shown in Figure 2 and Table VIII. Figure 2 suggests that the effect of practice in the experiment was a marked increase in accuracy for resolutions of 11 and 14 lines. However, despite the increased accuracy at the lower resolutions, the general relation between accuracy and resolution was similar to that of Part I in that the break in the curve occurred at 17 lines per symbol height. Another finding for Part II which also might be attributed to practice is noted in Table VIII where the standard deviations indicate a decrease in differences among subjects in their ability to identify the symbols; the decrease is specially marked for resolutions of 11 and 14 lines.

A third finding which might be attributed to practice is noted in Tables X through XII where a marked reduction occurred in the number of errors among map symbols denoting different branches. For example, at a resolution of 11 lines, confusion among units of different branches for the selected set of symbols contributed 17 percent to the total error in contrast to 44 percent for Part I, while confusions among units of the same branch contributed approximately 57 percent to the

Table IX. Speed of Identification in Seconds for Part II

Subjects	Lines Per Symbol Height				
	11	14	17	20	23
1	3.39	1.99	1.27	1.12	1.17
2	1.41	1.25	1.04	1.06	.96
3	3.54	2.93	1.05	1.21	1.01
4	2.37	1.62	1.17	.96	.98
5	2.33	1.72	1.35	1.29	1.17
$\bar{X}$	2.61	1.90	1.18	1.13	1.06
SD	.78	.56	.12	.11	.09

Table X

Symbol Confusions for a Resolution of 11 Lines for Part II

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1		9																													9
2																															0
3									1	4	3																				8
4			3						4	2																					9
5						1																				1					2
6					3																										3
7														6	5																11
8																															0
9			3	6																										1	10
10				1							1																			9	11
11																															0
12													5																		5
13												7																			7
14																															0
15							1							2			1													2	6
16																	1														1
17																4														1	5
18						1																									1
19																		6													6
20																					3										3
21																				10											10
22																													2		2
23																															0
24																									2						2
25																								4			2				6
26																															0
27																								5	11						16
28														1																	1
29																															0
30															1	1															2
	0	9	6	7	3	2	1	0	5	6	4	7	5	9	6	5	2	6	0	10	3	0	0	9	13	1	2	0	2	13	136

Table XI

Symbol Confusions for a Resolution of 14 Lines for Part II

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1		6																													6
2	1																														1
3				1																											1
4			4																												4
5						1																									1
6					1																										1
7																															0
8					1																										1
9				2																											2
10				2																										8	10
11																															0
12																															0
13																															0
14																															0
15																															0
16																															0
17																															0
18																															0
19																															0
20																					3										3
21																				5											5
22																															0
23																															0
24																									1						1
25																								4							4
26																															0
27																								2							2
28																															0
29																															0
30																															0
	1	6	4	5	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5	3	0	0	6	1	0	0	0	0	8	42

Table XII

Symbol Confusions for a Resolution of 17 Lines for Part II

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1																															0
2	2																														2
3																															0
4			1																												1
5						1																									1
6																															0
7																															0
8																															0
9																															0
10																														2	2
11																															0
12																															0
13																															0
14																															0
15																															0
16																															0
17																															0
18																															0
19																															0
20																															0
21																				5											5
22																															0
23																															0
24																															0
25																								1							1
26																															0
27																															0
28																															0
29																															0
30																															0
	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	1	0	0	0	0	0	2	12

Table XIII

Symbol Confusions for a Resolution of 20 Lines for Part II

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1																															0
2																															0
3																															0
4																															0
5																															0
6																															0
7																															0
8																															0
9																															0
10																															0
11																															0
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15																															0
16																															0
17																															0
18																															0
19																															0
20																															0
21																				4											4
22																															0
23																															0
24																															0
25																															0
26																															0
27																															0
28																															0
29																															0
30																															0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	4

total error in contrast to 27 percent for Part I. At a resolution of 14, 17, 20, and 23 lines, there were no confusions among the units of different branches, and all of the errors occurred among units of the same branch.

The speed of identification obtained for Part II is shown in Figure 3 and Table IX. Figure 3 shows that the subjects were faster at each resolution than they were in Part I. However, the general relationship of speed of identification and resolution is the same as that for Part I in that the break in the curve occurs at 17 lines per symbol height.

In summary, with practice the subjects did better at 11 and 14 lines than they did in Part I, but they still did not improve enough to warrant lowering the recommended minimal resolution from 17 lines to 14 lines. The subjects improved markedly in their ability to identify symbols of different branches at 14 lines, but they still continued to confuse units of the same branch at this resolution. The latter errors were reduced appreciably, but not eliminated, with a resolution of 17 lines.

SECTION V

RESULTS FOR PART III

The results obtained after the vidicon tube and lens system had been replaced are shown in Figure 2. Identification accuracy at a resolution of 11 lines was now nearly as good as that found for 17 lines in Parts I and II. At 9 lines, accuracy decreased to approximately 88 percent.

Figure 3 shows a marked decrease in identification time at 11 lines over that found in Parts I and II. However, in contrast to accuracy of identification, the subjects did not respond as fast at 11 lines in Part III as they did at 17 lines in Part II.

A student "t" test indicated a significant difference ($t = 4.04$, $.05 > p > .02$) in accuracy of identification between a resolution of 11 lines in Part II and a resolution of 11 lines in Part III. A similar test for speed of identification failed to show a significant difference ($t = 2.72$, $.10 > p > .05$) in results in Parts II and III.

The results obtained at a resolution of 11 lines for the zoom lens versus the fixed focal-length lens are shown in Table XIV. Both speed of identification and accuracy of identification were better when the fixed focal-length lens was used, but statistical tests between lens systems failed to show any significant differences.

Table XIV. Speed and Accuracy of Identification of Symbols Displayed by Two Lens System

Subjects	Speed of Identification in Seconds		Accuracy of Identification in Percentage Correct	
	Fixed Focal-Length Lens	Zoom Lens	Fixed Focal-Length Lens	Zoom Lens
1	1.35	1.81	99	97
2	1.34	1.62	99	87
3	1.21	1.30	99	95
4	1.74	1.68	89	90
$\bar{X}$	1.41	1.60	96	92

The results in Part III suggest that when practiced subjects are shown a good quality display, a resolution of 11 lines per symbol height might be satisfactory.

SECTION VI

LIMITATIONS OF RESULTS

The findings for both accuracy and speed of identification in Parts I and II of the experiment indicated that the minimum acceptable resolution for viewing televised military symbols was 17 lines per symbol height. However, recommendations based upon these findings are limited for several important reasons.

First, one possible effect of practice in the identification of televised map symbols was the reduction in the percentage of errors among units of different branches. While practice seemed to have a major effect in reducing errors among units of different branches, it appeared to have a smaller effect on confusions among units of the same branch. The different effects of practice on these two types of confusions is not too surprising because the correct identifications of units of different branches depends upon the discrimination of larger, and thereby better resolved, symbol detail while the correct identity of symbols of the same branch depends upon the discrimination of smaller, and thereby less well resolved, detail. With practice, large detail can be accurately distinguished at a resolution of 14 lines. On the other hand, when the discrimination involves the detection of small symbol detail, resolution needs to be increased to

17 lines before most of these confusions disappear. When the basic rectangular unit is resolved by 17 lines, small detail such as the "xx" and "||" of symbols 3 and 4, the "||" and ".." of symbols 5 and 6, and so on, are resolved by 3 to 4 active scan lines and have a visual size of 5 to 6 minutes of arc. Generalizations about map symbol resolution must therefore account for the amount of practice the subject has had with the special details of the symbols he is trying to identify. Since this is difficult, in any practical situation, each case will probably present its own requirements.

Recommendations for television displays based on the findings of Parts I and II of the experiment are (a) the basic rectangular unit should be resolved by no fewer than 17 lines for observers with little practice in the identification of military symbols, (b) the resolution of the basic rectangular unit may be decreased to as few as 14 lines for practiced observers, and (c) the small detail of military symbols, like the markings for the size of the unit, should be displayed with a resolution of at least 4 lines and with a visual size of 5 to 6 minutes of arc.

A second and perhaps more important reason for limiting recommendations based upon the findings in Parts I and II has to do with the equipment problems encountered during that investigation. The problems were such that the quality of the display was questionable

and the findings in Parts I and II must be viewed as conservative in that good identification at resolutions lower than 17 or 14 lines is possible with a display of maximum quality, as was shown by the results of Part III. At the same time, it should be recognized that many television systems operating in applied settings will not provide a display of maximum quality. Improper adjustments of the camera, monitor, associated control units, and optical units as well as gradual aging of the vidicon and picture tubes will all lead to a display with less than maximum quality.

In the present study, it appears that the problem encountered in achieving a display of maximum quality in Parts I and II was caused by two factors; a deteriorated vidicon tube and a slight defocussing caused by a zoom lens on the camera. When both the vidicon and the lens were replaced, the subject's performance improved significantly at a resolution of 11 lines. In fact, after these units had been replaced, the subject's accuracy of identification at 11 lines was as good as his performance at 14 lines in Part II.

A further question remained about the primary cause of poor performance in Parts I and II; the vidicon tube or the zoom lens. When the lens system alone was evaluated, the subjects did better with the fixed focal-length lens than they did with the zoom lens, although the amount of improvement was not statistically significant.

Both supplemental studies of Part III indicated that the poor quality display was probably caused by both the vidicon tube and the lens system. The zoom lens by itself caused a slight impairment in identification, but when it was operating in conjunction with a poor vidicon tube, a significant decrease in performance occurred.

Generalizations about symbol resolution must therefore account for potential variations in optical and electrical components of particular television systems. Since these factors are difficult to determine in most applied situations, particularly in view of possible variations in electrical components, each case presents its own requirements, and for this reason, each application should be tested individually.

A third reason for limiting recommendations based on the findings of this study is the small number of military symbols studied. In the present experiment, a total of 30 symbols was used. In practice the number of symbols which might be displayed is much greater, and symbol identification may be expected to depend upon the discrimination of detail different from that of the symbols used in the present study.

A final reason which limits generalizations of these findings is that the symbols were displayed with a higher brightness contrast than would be expected in most applied situations, particularly when the symbols are drawn or printed on military maps where, because of different

brightnesses of the background terrain, the brightness contrast for most symbols would probably vary from very low to intermediate values.

In summary, all of the above factors suggest that for one reason or another most applied situations will require a minimal resolution of at least 17 lines for optimal speed and accuracy of identification of map symbols. These results have identified certain resolutions, visual sizes, television equipment components, and observer experience that should be considered carefully in the design of military displays. The data indicate quite clearly that because of the many factors which may affect the viewer's ability to identify televised symbols, performance tests like those described in the present study should be used in order to evaluate each individual closed-circuit television system. If individual testing of a television system is impractical, then the recommendations made in Parts I and II may be taken as lower limits for the resolution of military map symbols.

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M. Marsetta

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13. ABSTRACT

The speed and accuracy with which five subjects identified military map symbols were determined with five different resolutions in lines per symbol height on a television monitor in three experiments. The first two experiments indicated that the minimum acceptable resolution is approximately 17 lines even after considerable practice. The third experiment indicated that a slightly lower resolution is permissible only with an optimum contrast of detail and a carefully selected and maintained television system. Recommendations are made for field installations.

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